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ARMAMENT RESEARCH DEPARTMENT

Explosives Report No. 638/44

September, 1944.

Target Damage by Munroe Jets

Protection of steel targets by non-metallic substances,  
with special reference to oxidising agents.

INTERIM REPORT

by

C.E. Roberts and A.R. Ubbelohde

References: H. 3214/42(3)  
O.B. App. 737

SUMMARY

Object and Scope of the Report

In view of the recent Australian statements, experiments have been made with Munroe Jets from 45° steel cones on the 1.3/8" diameter scale, passing through various layers of oxidising substances, before attacking the main target of massive steel. The protection afforded is compared with that from equivalent thickness and equivalent weight of mild steel, and from various other non-metallic materials.

Experimental methods

Standard hollow charges were used at one charge diameter away from layers of the following materials:

Barium Nitrate (cast and pressed)  
Barium Chlorate (pressed and cemented)  
Barium perchlorate (pressed)  
Potassium perchlorate (pressed)  
Lead peroxide (pressed)  
Sodium chloride (pressed, for comparative purposes)  
Sodium carbonate decahydrate (pressed)  
1" mild steel (for comparative purposes)

These materials were contained in boxes of thin timplate in contact with the massive steel plate, and were faced with thin timplate. Residual damage in the massive steel target was determined by measuring crater volume and crater depth, and the protection afforded was compared on a thickness basis, and a weight basis, with that from one inch of mild steel.

Experimental Results

1. Non-metallic substances protect the main target by reducing both the depth of penetration and the volume of the crater (see Table I). Table II contains the following:
2. The thickness of material which reduces the penetration by the same extent of 1" of mild steel (Column 4).
3. The weight of material which reduces the penetration by the same extent as 1" of mild steel (Column 5).
4. The comparative protection to be expected from 'plastic' materials owing to the difference of density compared with mild steel (Column 6).

/Conclusions

## Conclusions

The following conclusions are subject to the limited number of experiments yet carried out:

1. Expressed on a weight basis, sodium carbonate decahydrate appears to be the most favourable protecting material yet investigated, and is definitely more effective than barium perchlorate, dry sand, water, or polymethyl methacrylate. This conclusion may depend on the size of the crystals used.
2. Barium perchlorate, dry sand, barium chlorate, and possibly barium nitrate and potassium perchlorate have a more efficient mechanism of arresting Munroe jets, than materials capable of 'plastic' flow, such as metals.
3. On a weight basis, the additional protection from a layer of the oxidising salts barium perchlorate or barium nitrate does not appear to be sufficient, compared with that due to materials such as sodium carbonate, dry sand, water, or methyl methacrylate, to justify further investigation of oxidising agents until more experimental details are available in support of the Australian claim.
4. The use of protective materials, such as dry sand, washing soda, or other salt hydrates, for arresting Munroe jets may warrant practical trials on defensive armour.

## Recommendation

As dry sand has been shown to be of high efficiency and as it is insoluble in water, if desired, a practical trial might be carried out with the sand retained against the surface of the main plate, for example.

## REPORT

### The protection of steel targets by non-metallic substances

#### A. Introduction

1. The thickness of material with the same arresting power as one inch of mild steel has previously been determined in two ways:-

(a) The same type of jet is fired into "semi-infinite" targets of mild steel, and of the material under test. From the ratio of the thicknesses penetrated, the thickness of material equivalent to one-inch of mild steel is calculated.

Results calculated in this way from data on copper jets (Kolsky, Shearman & Snow, A.C. 4638/S.C.50) are given in Table II.

(b) The reduction in damage to a steel target by interposing one inch of mild steel in the path of the jet, is compared with the reduction due to various thicknesses of the material under test, so as to calculate what thickness of material is equivalent to one inch of mild steel (Evans and Ubbelohde, A.C.1911, Phys/Ex:245). To avoid extensive extrapolation in this method, as far as possible the thicknesses tested experimentally are chosen so as to give a reduction in damage, similar to that obtained from one inch of mild steel. Data obtained in this way are included in Table II.

2. Theoretical calculations on the depth of penetration "t" of Munroe jets into substances capable of plastic flow under pressure, such as metals, show that

$$t = L \lambda \sqrt{P_j / P_r} \quad \text{where } L, \lambda \text{ and } P_j \text{ are}$$

constants of the jet at constant stand-off, and  $P_r$  is the density of the target material (Hill, Mott and Pack, A.C.6024, S.C. 76).

So far as this formula applies to non-metallic materials, the thickness equivalent to one inch of mild steel, determined by method 1(a), will be

$$\text{equivalent thickness} = \sqrt{(P_{\text{steel}} / P_{\text{target}})} \quad (1)$$

$$\text{or equivalent thickness} \times (P_{\text{target}} / P_{\text{steel}})^{\frac{1}{2}} = 1 \quad (1) A$$

A further consequence of this theory is that for targets capable of plastic flow, the weight equivalent to steel will be

$$\text{equivalent weight} = \text{equivalent thickness} \times P_{\text{target}} / P_{\text{steel}}$$

$$\text{or equivalent weight} = \sqrt{(P_{\text{target}} / P_{\text{steel}})} \text{-----} (2)$$

This means that to have the target as light as possible, for a given protection, THE DENSITY OF TARGET MATERIAL SHOULD BE CHOSEN TO BE AS LOW AS POSSIBLE.

Calculations of how far formula (1A) applies to the non-metallic substances for which data are available are shown in the last column of Table (2). When the figures in this column are greater than unity, the target material is less effective than a plastic material of equal density. When they are approximately equal to unity (as for water, beeswax, and methyl methacrylate), the substance is of the same effectiveness in protection, as a plastic material of the same density. Finally, when these figures are less than unity, as for dry sand, and barium chlorate, the material is more effective than any 'plastic' equivalent, and a smaller weight is required to arrest the jet.

#### B. Protective power of oxidising agents

The main object of the present experiments was to test an Australian claim (see references above) that oxidising materials, in particular barium nitrate, were specially effective in arresting Munroe Jets. In the course of the work, comparisons have been made with other non-metallic target materials.

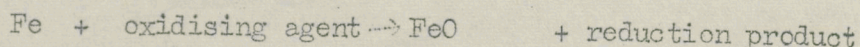
##### Experimental methods:-

Targets. No experimental details were available in support of the Australian claim. Tests were therefore made by pressing or casting various oxidising materials into boxes of thin tinplate, but this technique may call for revision when more information is available. In most cases layers one inch thick were prepared, but in some cases thicker layers were used. The top of the layer was protected from any scattering effect which might arise from the nearby detonation of explosive, by a thin layer of steel (26 gauge).

'Sandwiches' of the materials chosen were placed in immediate contact with targets of massive mild steel, and a Munroe jet from a 45° steel cone was fired at a stand off of 1D. In general, it was not possible to fire more than duplicate charges in these preliminary experiments.

Oxidising Substances:- In addition to barium nitrate, which was used in the cast and pressed form, the other readily available oxidising agents listed in Table I were selected so as to give a high heat of reaction for

equation



since it was thought that a high heat of reaction would favour oxidation of the jet.

In most cases, it was convenient to use these substances in the hand pressed state. A litharge/glycerol cement was tested in one case as a binder. But further tests on binders have been deferred until the special value of oxidising agents for arresting Munroe jets has been proved. Some difficulty may be found in selecting such binders, since many organic binders would form sensitive explosive mixtures with the oxidising materials listed.

Other target materials:- To test the special value of the oxygen content, comparative tests were included with NaCl. Data on dry sand (Table 2) had been previously obtained. Data on sodium carbonate decahydrate were included in view of the favourable stopping power of water.

Experimental Results. Direct measurements are given in Table I, and calculated values of equivalent thickness in Table 2.

The following points may be noted:-

1. From the data in Table I, it will be seen that the reagents tested reduce both the depth of penetration and the crater volume. It is not yet clear whether this reduction in crater volume is merely due to the loss of part of the jet, leaving the remainder to pass through unaffected, as in the 'plastic' mechanism (see above) of target penetration, or whether the oxidising materials also act by wearing away the periphery of the jets.
2. From the data in Table 2, which are arranged in order of ascending equivalent weight of target (5th column), it will be seen that the equivalent thickness of the best oxidising material found ( $\text{Ba}(\text{ClO}_4)_2$ ) is not much less than that of dry sand.

The range of values obtained with barium nitrate (cf. also Table I) suggest that the physical form of the material may be of considerable importance, and may require further investigation.

3. Attention is drawn to the low equivalent weight of dry sand, which is more effective as a stopping agent than plastic materials, possibly because of the numerous discontinuities it introduces in the path of the jet. Water is also effective at a fairly low equivalent weight, but here this is entirely due to the low density, since the material behaves as 'plastic'. Polymethyl methacrylate has mechanical properties which might also make it of value as a protective agent of lower weight than homo-armour, though in all these cases it is necessary to consider the protection afforded against A.P. shot, as well as that against Munroe jets.

4. In view of the favourable equivalent weight of water as a stopping medium for Munroe jets, experiments were planned with salt hydrates of high water content, which would be more convenient to use in practice. Tests with sodium carbonate decahydrate suggest that this may be a promising line of investigation in designing armour for defence against Munroe jets. From the data in Table 2 (column 5), the saving in weight from a layer of a salt hydrate may be very considerable. The effect of varying the crystal size still requires investigation. Further work is in hand to investigate points 3 (effect of discontinuities) and 4 (effect of salt hydrates).

#### Comments

1. From the data recorded, although oxidising agents can be found of low equivalent weight, there does not seem to be sufficient practical advantage, compared with materials such as dry sand, to warrant further trials at the present time.

This conclusion may need revision when more data are available about the Australian set up of target or about any special jets used.

2. The attention of designers of defence against attack by hollow charges is drawn to the comparative data in Table 2.

3. The suggested use of salt hydrates for arresting Munroe jets warrants consideration from the practical aspect. Special measures would have to be taken to combat their solubility in water.

TABLE I

Jet from 1.3/8" diameter 45° M.S. cone at 1D from the protecting layer in contact with massive mild steel

Residual target damage in mild steel (mean of two experiments)

Protecting Layer	Crater Depth (inches)	Crater Volume (cc)
No obstruction	3.5	9.0
1" M.S. plate	2.0	2.4
1" pressed NaCl (density 1.37 gm/cc.)	3.2	5.4
1" pressed PbO <sub>2</sub> (density 3.3 gm/cc.)	2.8	3.2
1" pressed KClO <sub>4</sub> (density 1.35 gm/cc.)	2.8	4.8
1" cast Ba(NO <sub>3</sub> ) <sub>2</sub> (density 4.0 gm/cc.)	3.0	4.9
Ditto 2.6 gm/cc.	2.5	3.9
Ditto, pressed 2.1 gm/cc.	2.9	3.5
1" pressed Ba(NO <sub>3</sub> ) <sub>2</sub> (density 2.7 gm/cc)	3.0	4.4
Ditto cemented with PbO/glycerin	3.1	5.6
Ditto 2" pressed, density 1.8 gm/cc.	1.6	2.0
1" pressed Ba(ClO <sub>4</sub> ) <sub>2</sub> (density 1.28 gm/cc.)	2.4	5.1 (single experiment)
1" pressed Na <sub>2</sub> CO <sub>3</sub> ·10 H <sub>2</sub> O (density 0.5 gm/cc)	2.9	5.7

/Table 2.

TABLE II

Thickness and weight of material equivalent to 1"  
of mild steel

Material	Density	Physical Form	Equiv. Thickness Mild - Steel = 1 inch	Equiv. Weight Mild Steel = 1 inch	Equivalent 'Plastic' effect
$\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$	0.5	Hand stemmed (through 30 mesh)	2.5	0.16	2.0
$\text{Ba}(\text{ClO}_4)_2$	1.3	Cryst. (through 50 mesh), hand stemmed.	1.37	0.23	0.56
Sand (dry) (2)	1.5	Through 60 mesh, hand stemmed.	1.6	0.31	0.7
$\text{Ba}(\text{ClO}_3)_2$	1.8	Hand stemmed (through 50 mesh) 2" thick)	1.59	0.36	0.8
ditto	1.7	(1" thick)	2.9	0.63	1.35
Water (2)	1.0	water or ice	3.0	0.38	1.0
$\text{KClO}_4$	1.4	cryst. (through 50 mesh), hand stemmed.	2.1	0.37	0.89
Beeswax (2)	1.0	cast	3.3	0.42	1.1
Polymethyl methacrylate (1)	1.2	block	2.8	0.43	1.1
Wood (1)	(0.6)	-	9.3	0.46	2.6
Polythene (1)	(0.9)	block	5.0	0.57	1.7
$\text{Ba}(\text{NO}_3)_2$	4.0-2.1	cast or pressed	2.9-1.5	1.5-0.5	0.9-2.0
$\text{PbO}_2$	3.3	(approx. 100 mesh) hand pressed	3.3	0.88	1.36
$\text{NaCl}$	1.4	(through 30 mesh) hand pressed	5.0	0.89	2.11

(1) Extracted from Kolsky, Shearman & Snow, A.C. 4638, S.C. 50

(2) Extracted from Evans & Ubbelohde, A.C. 1911, Phys. Ex. 245